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STORAGE

THE BUFFER ACTION OF SOME BURMA SOILS

BY

J. CHARLTON, M.Sc., A.I.C

Agricultural Chemist, Burma

AGRICULTURAL RESEARCH INSTITUTE, PUSA

PRINTED AND PUBLISHED FOR

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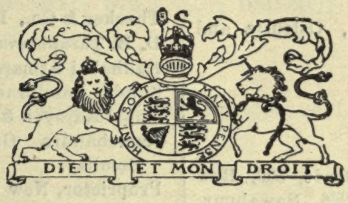

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THE BUFFER ACTION OF SOME BURMA SOILS

BY

J. CHARLTON, M.Sc., A.I.C.,

Agricultural Chemist, Burma.

[Received for publication on the 7th April, 1924.]

I. INTRODUCTORY.

In rice producing countries such as Lower Burma where the rainfall averages ninety inches or more per annum, the annual loss of calcium carbonate from the soil is of great importance. It is well known that the majority of these soils are sour, and it is to be expected that they will gradually become more infertile for this reason alone, apart from other causes. The probable rate at which sourness will develop is, therefore, a very important matter.

Carbonates are, of course, not the only substances in the soil which resist the tendency towards sourness. Humus and other colloids resist change towards a more acid or more alkaline reaction, whereas carbonates resist only change towards an acid medium. Although, only substances resisting changes of reaction caused by both acids and alkalis can properly be called *buffers*, it is convenient to include carbonates because in general carbonates are the most important substances which prevent sourness in soils. To measure the amount of individual buffers in the soil is not possible because of the complexity of the problem. In the method developed, however, it is shown that useful information may be obtained by shaking soil with dilute acid and alkali and measuring the pH value of the soil solution so obtained. Arbitrary pH limits have been fixed at 4·5 and 9·5 and the behaviour of the soil examined between these limits.

Olof Arrhenius[1] obtained titration curves for certain soils, chiefly oriental. He did not deduce any expression for the *buffer action* of these soils. Buffer action or buffer effect may be defined as the rate of change of pH with addition

[1] Arrhenius, Olof. *Soil Science*, XIV, No. 3, pp. 223–232.

of acid and alkali. For equal additions of acid or alkali, soils showing a large buffer action will exhibit small changes of pH, while soils having a small buffer action will suffer relatively large changes of pH. Arrhenius found a general correlation between the titration curve and the fertility of the soil examined. A large buffer action usually indicated a good soil and small buffer action a poor soil.

Estimations of lime requirement such as that of Hutchinson and McLennan[1] are particular cases of the titration method in which the reaction of the soil is adjusted to a particular pH value. It has been shown by Warth and Po Saw[2] that the concentration of carbon dioxide in the calcium bicarbonate used causes large differences in the absorption of calcium carbonate, and they have developed a method of calculating lime requirement from the ratio $\frac{CaCO_3}{CO_2 \text{ in solution}}$ when equilibrium between soil and bicarbonate solution has been attained. For this purpose a typical neutral soil (Pwinbyu) was taken as standard. Further reference to this soil will be made subsequently.

In the method developed by Christensen[3] the growth or failure to grow of azotobacter demarked soils into two classes. In soils more alkaline than pH 5·9—6·0 azotobacter could grow whereas if more acid they failed to grow.

The advantages of titration curves as compared with actual lime requirements are apparent since some idea of the amount of buffers in the soil may be inferred from the curves.

II. EXPERIMENTAL.

To a series of flasks, each containing 20 grm. of air-dried soil which had passed the 3 mm. sieve, 100 c.c. of distilled water or 100 c.c. of dilute acid or alkali were added and the flasks closed with rubber stoppers. The flasks were then shaken in a shaking machine for a definite period at constant temperature. The soil solution was decanted, centrifugalised until clear and the pH value determined by Gillespie's method[4] using the comparator described by him. It was found that careful definition of the experimental conditions was necessary before consistent results could be obtained.

1. Acid and alkali used.

H_2SO_4 was used in all cases for the acid series. No objection to its use was found as it gave an extract which was always easily centrifugalised

[1] Hutchinson and McLennan. *Jour. Agri. Sci.*, 1915, 75.
[2] Warth, F. J., and Maung Po Saw. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. V, No. 6.
[3] Christensen, H. R. *Tidsskr. Plantearl*, 1916, pp. 231–283.
[4] Gillespie, L. J. *Soil Science*, Vol. IX, No. 2, pp. 115–136.

to a clear solution. In the case of heavy calcareous soils, the addition of a drop or two of dilute H_2SO_4 is advantageous, since a clear extract is thereby more easily obtained and the pH value is altered only to a minute extent or not at all. The case of alkali is quite different. NaOH, Na_2CO_3, $Ba(OH)_2$, MgO, KOH and NH_4OH were used. Results varied according to the soil under examination. The cases of Pwinbyu, Palan and Padu soils will be considered.

(*a*) *Pwinbyu Soil.* Ten cubic centimetres each of N/10 Na_2CO_3, KOH, NaOH, $Ba(OH)_2$ and 0·02 grm. of solid MgO were each made up to a volume of 100 c.c. with distilled water and added to a series of flasks each containing twenty grams of air-dried Pwinbyu soil. The flasks were then shaken for twelve hours in a shaking machine at constant temperature (30°C.), the soil extract centrifugalised in corked vessels and the soil solutions examined. The MgO treated sample was quite clear, the Na_2CO_3 and KOH samples nearly so, while the NaOH and $Ba(OH)_2$ treated samples were slightly turbid.

(*b*) *Palan* (*Kyauktan*) *Soil.* Equivalent amounts of MgO and NaOH solution were tested against Palan soil in the same way as in the case of Pwinbyu soil. The soil solutions were shaken for half an hour and for two hours in each case after which the soil extracts were centrifugalised. The pH values obtained varied considerably although equivalent amounts of MgO and NaOH had been used (Table I).

TABLE I.

Palan (*Kyauktan*) *soil. Behaviour with MgO and NaOH.*

MgO			NaOH		
c.c. N/10 MgO added (as solid)	REACTION FOR		c.c. N/10 NaOH added	REACTION FOR	
	30 min.	2 hr.		30 min.	2 hr.
nil	5·7	5·70	nil	5·70	5·70
0·5	6·6	6·25	0·5	5·85	5·75
1·0	7·4	7·10	1·0	6·05	5·90
2·5	8·8	7·90	2·5	6·35	6·35
....	....	...	5·0	7·10	6·90

Results were as expected. Owing to the slight solubility of MgO, the time of reaction is very important. Whereas addition of nil to 5·0 c.c. N/10 NaOH gives practically the same pH value in either half an hour or two hours, in the case of 2·5 c.c. N/10 MgO there is a very marked difference. In case MgO is used the reaction must therefore be continued for a long period before equilibrium is obtained. It is not to be concluded that equilibrium is attained with NaOH in two hours. Such is not the case. The duration of reaction is treated later. In the present case of Palan soil the only inference is that in short periods different alkalis give different pH values.

(*c*) *Padu Subsoil.* Ten cubic centimetres each of N/10 NaOH, Na_2CO_3, $Ba(OH)_2$ KOH, NH_4OH and 0·02 grm. MgO were made up as before to a volume of 100 c.c. and added to a series of flasks each containing 20 grm. of Padu subsoil. The flasks were then shaken as in the previous cases but for twelve hours and the soil extracts obtained. In these soil extracts the pH values of only the MgO and $Ba(OH)_2$ treated samples could be read directly, all other extracts being very highly coloured largely owing to the presence of iron. Further, whereas in the case of NaOH the more alkali added, the deeper the colour of the soil solution obtained, in the case of MgO and $Ba(OH)_2$ the reverse is the case within wide pH limits. On adding sufficient MgO or $Ba(OH)_2$ to adjust the soil solution to pH 8·0—pH 9·0, water clear extracts were obtained.

The low solubility of MgO is a disadvantage for the practical part of the work and hence $Ba(OH)_2$ was selected as the most suitable alkali for all-round work. $Ba(OH)_2$ solution can be easily obtained at a strength of about 0·4 normal at ordinary temperatures and this is quite suitable for the work.

2. Duration of reaction with acid and alkali.

The only calcareous soil with which detailed experiments were made was Mandalay soil. This contains about one per cent. of carbonates of calcium and magnesium. It was found that the whole of the carbonates were not acted upon in less than about twelve hours at a constant temperature of 30°C., the soil and acid being constantly agitated in a shaking machine during the whole of this period. Tables II—V give the pH values of Mandalay, Pwinbyu, Hmawbi and Palan soils after reaction for thirty minutes, one, two, six, twelve and twenty-four hours respectively. The same results are plotted as titration curves in Charts I—IV showing only the half hour and twenty-four hour results for the sake of clearness. In all cases results are calculated to 100 grm. soil dried to constant weight at 100°C.

Table II.

Mandalay Farm Soil. pH value obtained with addition of H_2SO_4 and $Ba(OH)_2$. Reaction temperature 30°C. Results calculated to 100 grm. dry soil.

c.c. N.H_2SO_4 added	nil	0·53	1·32	2·64	5·28	7·92	10·56	13·20	15·84	18·48	21·12	23·76
30 minutes	8·05	7·95	7·60	7·2	6·45	5·75	4·90	<4·05	<4·05	..	..	..
1 hour ..	8·00	7·70	7·60	7·2	6·45	5·75	4·90	<4·05	<4·05	..	..	..
2 hours ..	8·05	7·85	7·65	7·4	6·60	6·05	5·35	4·70	<4·05	..	..	..
6 hours ..	8·05	..	..	..	7·20	6·50	5·90	5·70	5·10	4·6	<4·05	..
12 hours ..	8·05	..	..	..	..	6·80	6·35	6·05	5·65	5·0	4·60	4·25
24 hours ..	8·05	..	..	..	..	7·00	6·70	6·25	5·95	5·3	4·60	4·25

c.c. N.$Ba(OH)_2$ added	nil	0·96	1·11	2·4	2·78	4·8	5·55	7·2	8·33
30 minutes ..	8·05	8·4	..	9·4	..	>9·75	..	>9·75	..
1 hour ..	8·05	8·5	..	9·5	..	>9·75	..	>9·75	..
2 hours ..	8·05	8·5	..	9·5	..	>9·75	..	>9·75	..
6 hours ..	8·05	8·5	..	9·4	..	>9·75	..	>9·75	..
12 hours ..	8·10	8·3	..	9·0	..	9·55	..	>9·75	..
24 hours ..	8·05	..	8·3	..	9·0	..	9·5	..	>9·75

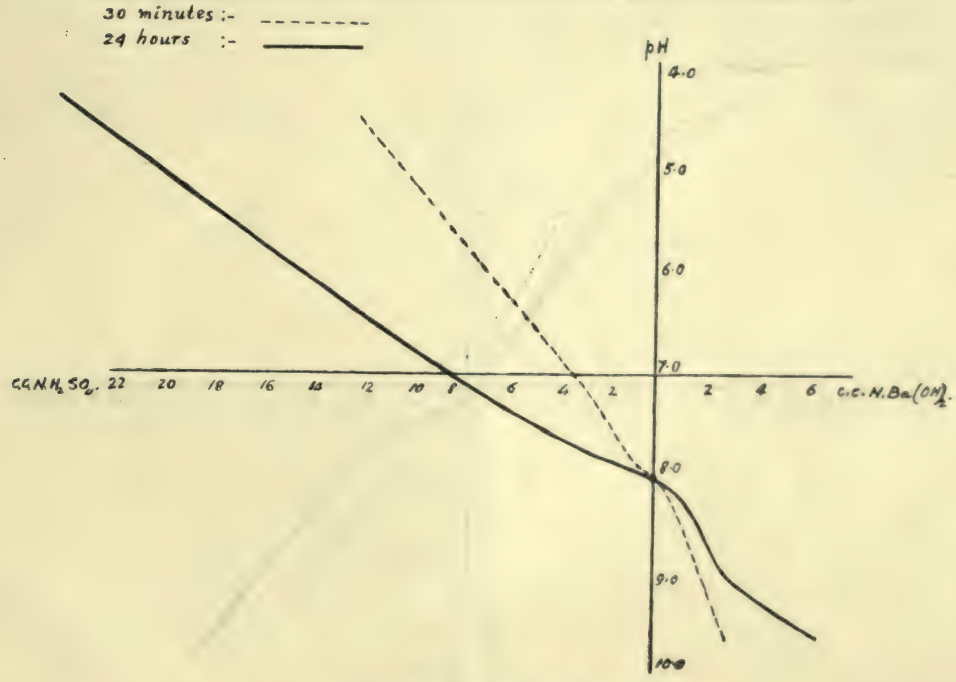

Chart I. Mandalay Soil.

Table III.

Pwinbyu Farm Soil. pH values obtained with addition of H_2SO_4 and $Ba(OH)_2$. Reaction temperature 30°C. Results calculated to 100 grm. dry soil.

c.c.N.H_2SO_4 added	nil	0·52	1·29	2·58	3·86	5·15	6·44	7·72	9·01	10·30
30 minutes ..	7·1	..	6·35	5·85	5·30	4·60	4·25	4·05	<4·05	..
1 hour ..	7·1	..	6·40	5·90	5·30	4·70	4·40	4·25	<4·05	..
2 hours ..	7·1	..	6·50	6·05	5·35	4·85	4·60	4·40	4·15	..
6 hours ..	7·2	..	..	6·25	5·85	5·50	4·85	4·50	4·15	<4·05
12 hours ..	7·1	..	..	6·25	5·85	5·30	4·90	4·70	4·45	4·20
24 hours ..	7·2	..	..	6·25	5·90	5·30	4·90	4·70	4·50	4·20

c.c.N.$Ba(OH)_2$ added	nil	0·99	2·47	4·95	7·42	9·89	12·36	14·845
30 minutes ..	7·0	7·2	7·6	8·50	9·3	9·55	>9·75	>9·75
1 hour ..	7·0	7·3	7·6	8·50	9·2	9·55	>9·75	>9·75
2 hours ..	7·0	7·4	7·7	8·40	9·3	>9·75	>9·75	>9·75
6 hours ..	7·0	7·4	7·7	8·30	9·2	>9·75	>9·75	>9·75
12 hours ..	7·0	7·4	7·6	8·30	8·9	9·50	>9·75	>9·75
24 hours ..	7·0	..	..	7·85	8·7	9·40	>9·75	>9·75

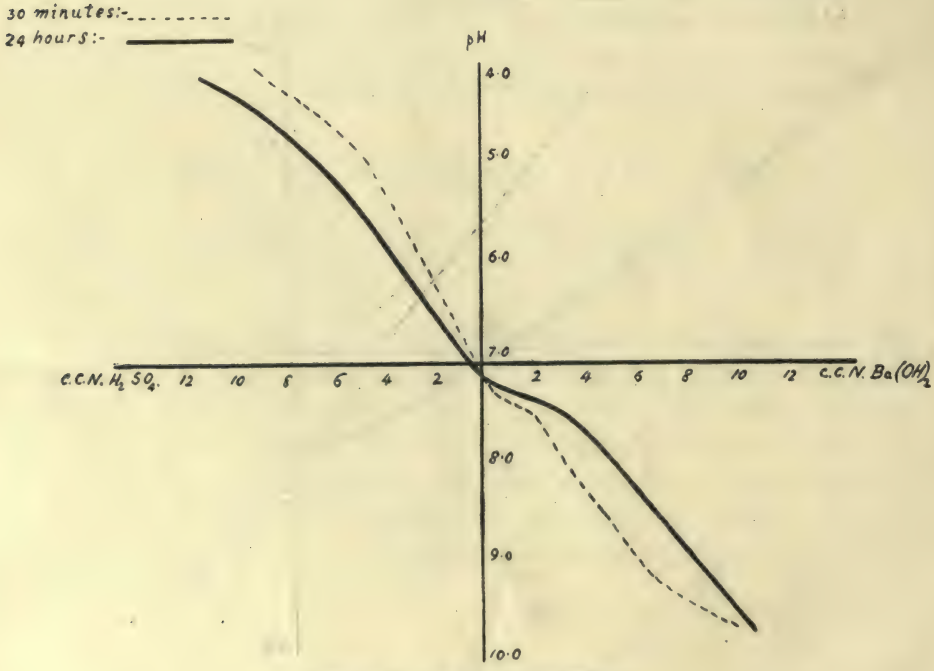

Chart II. Pwinbyu Farm Soil.

TABLE IV.

Hmawbi Farm Soil. pH values obtained with addition of H_2SO_4 and $Ba(OH)_2$. Reaction temperature 30°C. Results calculated to 100 grm. dry soil.

c.c. N.H_2SO_4 added	nil	0·13	0·26	0·51	1·28	2·56	3·85	5·01
30 minutes ..	6·05	6·05	5·40	4·9	4·40	4·05	<4·05	<4·05
1 hour ..	6·05	6·05	5·65	4·95	4·50	4·05	<4·05	<4·05
2 hours ..	6·05	6·05	5·55	5·1	4·50	4·20	<4·05	<4·05
6 hours ..	6·05	5·75	5·70	5·3	4·50	4·25	<4·05	<4·05
12 hours ..	6·05	6·05	5·70	5·3	4·60	4·25	<4·05	<4·05
24 hours ..	6·05	6·05	5·70	5·35	4·75	4·25	<4·05	<4·05

c.c.N.$Ba(OH)_2$ added	nil	2·46	2·85	5·70	5·93	7·39	8·54	9·85	11·14	12·31	14·24
30 minutes ..	6·15	6·8	..	..	7·60	8·50	..	9·2	..	>9·75	..
1 hour ..	6·15	6·7	..	..	7·60	8·40	..	9·2	..	>9·75	..
2 hours ..	6·15	6·7	..	..	7·60	8·40	..	9·0	..	9·55	..
6 hours ..	6·15	6·7	..	..	7·50	8·20	..	8·9	..	9·50	..
12 hours ..	5·95	6·7	..	..	7·45	8·15	..	8·5	..	9·50	..
24 hours ..	6·05	..	6·9	7·65	..	..	8·2	..	9·2	..	>9·75

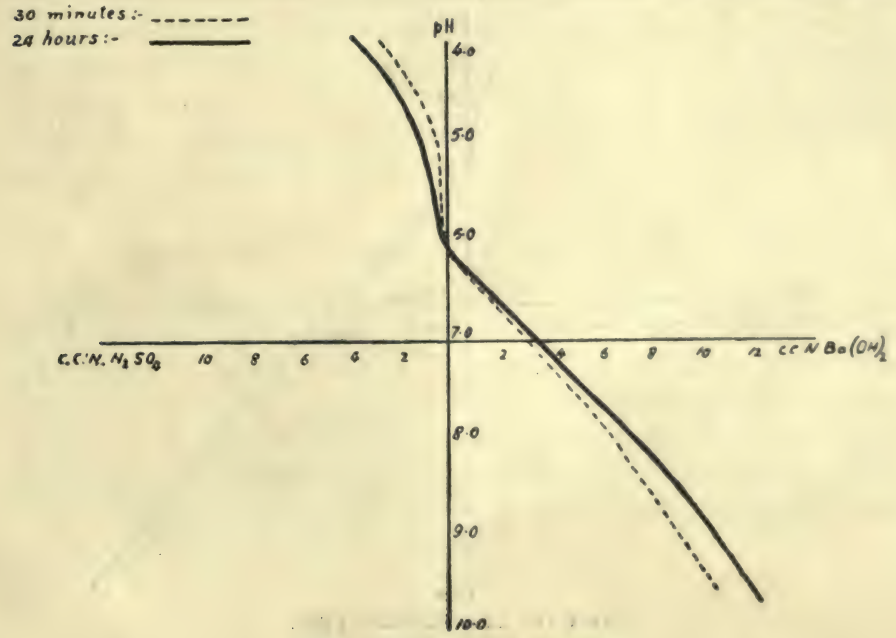

CHART III. Hmawbi Farm Soil.

Table V.

Palan (Kyauktan) Soil. pH values obtained with addition of H_2SO_4 and $Ba(OH)_2$. Reaction temperature 30°C. Results calculated to 100 grm. dry soil.

c.c. N.H_2SO_4 added	nil	0·13	0·27	0·54	1·34	2·68	4·02
30 minutes ..	5·75	5·55	5·3	4·6	4·05	<4·05	..
1 hour ..	5·75	5·55	5·2	4·8	4·25	<4·05	<4·05
2 hours ..	5·80	5·55	5·3	4·8	4·25	4·05	<4·05
6 hours ..	5·75	5·55	5·3	4·9	4·50	4·30	<4·05
12 hours ..	5·80	5·55	5·3	5·0	4·50	4·20	<4·05
24 hours ..	5·80	5·55	5·3	4·9	4·40	4·10	<4·05

c.c. N.$Ba(OH)_2$ added	nil	2·57	2·97	5·14	5·95	7·71	8·92	10·28	11·89	12·85	14·86	15·42
30 minutes ..	5·8	6·40	..	7·2	..	7·95	..	8·70	..	9·35	..	>9·75
1 hour ..	5·7	6·40	..	7·0	..	7·80	..	8·20	..	9·40	..	>9·75
2 hours ..	5·8	6·40	..	7·1	..	7·85	..	8·60	..	9·50	..	>9·75
6 hours ..	5·8	6·35	..	7·0	..	7·70	..	8·50	..	9·30	..	>9·75
12 hours ..	5·7	6·25	..	7·0	..	7·70	..	8·35	..	9·30	..	>9·75
24 hours ..	5·8	..	6·35	..	7·2	..	7·85	..	8·9	..	9·75	..

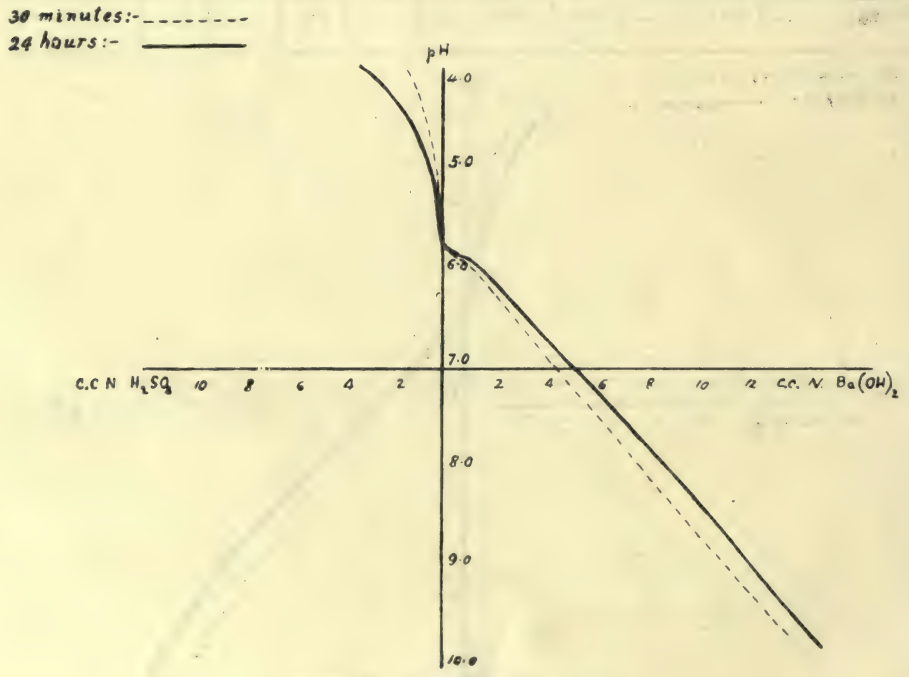

Chart IV. Plan (Kyauktan) Soil.

In drawing in the titration curves the general direction was followed. In this way it is possible that buffered action over small pH ranges is not shown.

From a consideration of Tables II—V and Charts I—IV it is clear that

(*a*) In the case of calcareous soils even when these do not contain more than one per cent. $CaCO_3$, equilibrium with dilute H_2SO_4 is not attained in less than 24 hours. It is probably not attained even in that period but the absorption of H_2SO_4 in about 12 hours is greater than that demanded by the presence of one per cent. $CaCO_3$ alone since to decompose one gram of $CaCO_3$ about 20 c.c. of $N.H_2SO_4$ are sufficient. Differences in the absorption of $Ba(OH)_2$ are small over a comparatively large time interval.

(*b*) In the case of neutral and sour soils, absorption of both H_2SO_4 and $Ba(OH)_2$ differ little even after reaction times so widely different as 30 minutes and 24 hours. The greater difference occurs in the case of the neutral soil both for acid and alkali.

It therefore appears advisable to continue the reaction for a period of 24 hours in all cases, although with soils which are known to be sour, very little error is introduced even if the reaction is allowed to proceed for 30 minutes only.

3. Temperature of reaction.

Detailed experiments to determine the difference due to changes of temperature of reaction were not attempted. Any difficulty due to temperature changes was avoided by constructing a wooden box lined with asbestos and fitting the same round the shaking machine. The temperature in all experiments was kept constant at 30°C. ± 1°C., *i.e.*, the lowest temperature which can be conveniently used in Mandalay.

4. Precautions necessary when using $Ba(OH)_2$ solution.

When measuring $Ba(OH)_2$ solution from a pipette it was found very necessary to avoid blowing down the pipette in the slightest degree, otherwise precipitation of $BaCO_3$ occurred. Errors due to this cause undoubtedly occurred in the earliest experiments but not in those quoted in this paper. Provided that care was observed, no precipitation of $BaCO_3$ occurred. Further, in all experiments quoted, the exposure of the soil solutions treated with $Ba(OH)_2$ was reduced to a minimum and while centrifugalising, the bottles were closed with rubber stoppers.

5. Dilution of soil solutions.

Theoretical evidence has been given to show that dilution of the soil solution may be practised without seriously altering the pH value obtained.[1] Dilution with distilled water both freshly boiled and otherwise was tried on certain soil solutions to confirm this (Table VI).

Table VI.

Dilution of soil solutions.

	pH Value					
Undiluted soil extracts	5·70	6·35	7·00	7·95	8·4	8·9
Extracts diluted with equal volume of distilled water of pH 5·4 ..	5·50	5·95	6·15	6·60	6·8	6·90
Extracts diluted with equal volume of distilled water of pH 7·0 ..	5·75	6·50	7·10	8·00	8·3	8·70
Extracts diluted with equal volume of distilled water of pH>9·75 ..	7·00	7·30	7·90	8·70	9·5	>9·75

At the time of the experiment, a sample of ordinary distilled water in the laboratory gave a pH=5·4; one that had been gently boiled for about five minutes and then quickly cooled gave a pH=6·9—7·0, while one that had been briskly boiled for thirty minutes and had then been quickly cooled gave a pH>9·75. This was due to solution of soda from the glass by the water. Unfortunately all the large glass vessels in the laboratory were of the same manufacture and hence the method of diluting turbid or highly coloured soil solutions for determination of the pH value could not be carried out. A centrifugal machine holding eight tubes each of 100 c.c. capacity was used to clear the turbid soil solutions and the pH values were determined direct. The centrifugal machine revolved at 2,000–2,400 revolutions per minute, and it was found that even heavy clay soils could be sufficiently cleared for the determination in a maximum of two hours' centrifugalising.

6. Recommended method.

To a series of flasks, usually eight, each containing twenty grams of air-dried fine soil which have passed the 3 mm. sieve, *i.e.*, soil for mechanical

[1] Sharp, L. T., and Hoagland, D. R. *Jour. Agri. Res.*, Vol. VII, p. 124.

analysis, 100 c.c. of dilute H_2SO_4 or $Ba(OH)_2$ are added in increasing concentration to seven and 100 c.c. of distilled water to the eighth. The flasks are closed with rubber stoppers and placed in a shaking machine with constant temperature device and shaken for twenty-four hours at 30°C. The soil solution is then decanted into centrifugal tubes which are thereupon closed with rubber stoppers and centrifugalised until clear. After decanting the clear solutions into clean dry vessels, the pH values are determined by Gillespie's method using a comparator to obviate difficulties due to slight colour or slight turbidity.

It is necessarily assumed that H_2SO_4 and $Ba(OH)_2$ behave similarly to other acids and alkalis respectively. This is possibly by no means the case. In particular the reaction with alkalis may be expected to differ since carbonates of sodium, potassium and ammonium are very soluble, whereas $CaCO_3$ and $BaCO_3$ are practically insoluble. Lime requirements made by using $Ba(OH)_2$ should, however, be comparable with those determined by using $Ca(HCO_3)_2$ since the solubilities of $BaCO_3$ and $CaCO_3$ are both very small and of the same order. Whether justifiable or not, this has been assumed largely because of the convenience of using $Ba(OH)_2$ solution.

III. NUMERICAL VALUES FOR BUFFER ACTION APPLIED TO BURMA SOILS.

G. Lehmann[1] has measured the buffer action of physiological solutions by means of the expression

$$\frac{b}{pH_1 - pH_2}$$

where pH_1 was the original and pH_2 the pH developed after adding a small quantity b of N/100 acid or alkali to ten cubic centimetres of the solution. For such solutions a buffer action of 8·0 indicated a strong, 0·5 to 4·0 a weak and 0·5 or less no buffer action. Blood gave a buffer action of 11·0.

The case of soil solutions is very different from that of physiological solutions in which only small changes of pH are usually measured. In the first place it has been assumed that the range of fertility of soils is from pH 4·5 to pH 9·5. A mathematical expression for the buffer action of a soil should fulfil the following :—

(*a*) The relative amounts of acid and alkali required to alter a soil from its existing pH value to pH 4·5 and pH 9·5 respectively should be shown.

[1] Lehmann, G. *Biochem. Zeits.*, 1922, 133, 30—45.

(*b*) There must be no possibility of confusing well buffered and poorly buffered soils. Hence the sum and not the difference of acid and alkali used must be shown.

(*c*) The difference between very sour and very alkaline soils must be indicated.

(*d*) It is undesirable to show absorption of acid and alkali as buffer action when it is known to be due to presence of free acids or free alkali. This condition is shown to some extent by the existing pH of the soil.

No simple algebraic expression fulfils the above conditions. It is therefore better to confine the problem to a simple issue. This is done by expressing the buffer action against sourness and alkalinity separately.

E.g. Buffer action against sourness $= \frac{\text{c.c.N.}H_2SO_4 \text{ used}}{X - 4{\cdot}5}$ per 100 grm. dry soil where X is the existing pH value of the soil. In the same way, the buffer action against alkalinity $= \frac{\text{c.c.N.Ba(OH)}_2 \text{ used}}{9{\cdot}5 - X}$ per 100 grm. dry soil where X is the existing pH value of the soil.

Under actual conditions the above method is justifiable since soils are becoming either more sour or more alkaline and trouble from one cause or the other, not both, may be anticipated. In the case of Lower Burma paddy soil the trouble is that of increasing sourness. For these soils, therefore, the value of the expression $\frac{\text{c.c.N.}H_2SO_4 \text{ used}}{X - 4{\cdot}5}$ indicates the type of soil but the total number of cubic centimetres of $N.H_2SO_4$ required to adjust the reaction of the soil from its existing pH value to pH 4·5 is a direct measure of the reserve fertility of the soil against sourness. In Table VII a list of Burma soils is given showing the buffer action against $N.H_2SO_4$ and $N.Ba(OH)_2$ per 100 grm. dry soil together with other data. Larger scale curves than those in Charts I—VII were drawn to determine these data more accurately.

The Lower Burma paddy soils quoted in Table VII are Hmawbi, Palan, Kyeinkagon, Kungyaunywa, Letpangin, Sinyokin and Magyibin, but the Akyab and Pyinmana soils may be considered along with these since they grow paddy under rainfall without irrigation. The Tonkan Forest Reserve soil is of the same type as Kyeinkagon and Letpangin and at some future date may grow paddy since this forest reserve is in the plains.

The total buffer action against $N.H_2SO_4$ shows that the Palan soil will probably be the first to become infertile through sourness (1·15), followed by Hmawbi (1·85) and Akyab waterworks (1·90). The most productive soils

TABLE VII.

Buffer action values of Burma soils.

Soil	Actual pH	Lime requirement per cent. from titration curves	Total buffer action against $N.H_2SO_4$	Buffer action against $N.H_2SO_4$ per 1·0 pH	Total buffer action against $N.Ba(OH)_2$	Buffer action against $N.Ba(OH)_2$ per 1·0 pH	Annual rainfall (Approximate)	Remarks
1. Mandalay ..	8·05	nil	22·50	6·34	5·50	3·80	....	Irrigated paddy calcareous water.
2. Pwinbyu ..	7·10	nil	9·00	3·46	10·00	4·17	....	Irrigated paddy calcareous water.
3. Hmawbi.. ..	6·05	0·1650	1·85	1·19	12·30	3·57	95″	Paddy under rainfall.
4. Palan	5·75	0·2600	1·15	0·92	14·10	3·76	112″	Paddy under rainfall.
5. Tatkon soil ..	6·90	0·0125	4·25	1·77	9·00	3·46	40″	All crops except paddy.
,, subsoil ..	6·90	0·0125	3·55	1·48	8·60	3·31		
6. Akyab—								
Waterworks soil ..	6·50	0·0350	1·90	0·95	5·85	1·95	195″–225″	Paddy under rainfall.
Waterworks subsoil	7·15	nil	3·20	1·21	5·25	2·23		
Mingan soil ..	5·85	0·1300	2·45	1·81	13·85	3·80		
Mingan subsoil ..	6·45	0·0575	3·25	1·67	13·60	4·46		

TABLE VII—*contd.*

Soil	Actual pH	Lime requirement per cent. from titration curves	Total buffer action against $N.H_2SO_4$	Buffer action against $N.H_2SO_4$ per 1·0 pH	Total buffer action against $N.Ba(OH)_2$	Buffer action against $N.Ba(OH)_2$ per 1·0 pH	Annual rainfall (Approximate)	REMARKS
7. Pyinmana—								
Highest land soil ..	6·50	0·0950	3·90	1·95	13·20	4·40	50″– 55″	Paddy under rainfall, also sugarcane.
Highest land subsoil	6·35	0·1150	3·25	1·76	13·30	4·22		
Lowest land soil ..	6·45	0·0500	3·65	1·87	9·20	3·02		
Lowest land subsoil	6·50	0·0700	3·75	1·88	9·20	3·07		
8. Tonkan—								
Forest Reserve soil..	6·35	0·1325	4·50	2·43	16·30	5·18	130″–140″ ?	Open teak forest (Plains).
Subsoil ..	6·10	0·2000	3·50	2·19	18·50	5·44		
9. Kyeinkagon—								
Soil	6·55	0·1100	6·40	3·12	14·90	5·05	130″–140″ ?	Medium to long lived paddies under rainfall.
Subsoil ..	6·80	0·0300	6·40	2·78	16·20	6·00		
10. Kungyaunywa—								
Soil	6·10	0·2500	5·00	3·13	34·80	10·23	130″–140″ ?	Medium to long lived paddy. District subject to floods.
Subsoil ..	6·60	0·0600	5·60	2·67	24·20	8·35		

11. Letpangin—								
Soil	6·60	0·0550	6·30	3·00	20·10	6·93	130″–140″ ?	Long lived paddy.
Subsoil ..	6·40	0·1500	3·90	2·05	17·80	5·74		
12. Sinyokin—								
Soil	6·20	0·1750	3·20	1·88	17·60	5·33	130″–140″ ?	Medium lived paddy. Very sandy soil.
Subsoil ...	6·35	0·1250	2·70	1·46	13·80	4·38		
13. Magyibin—								
Soil	6·15	0·2900	4·60	2·79	21·20	6·33	130″–140″ ?	Medium paddies. Soil not very fertile.
Subsoil ..	6·55	0·1250	5·00	2·44	19·60	6·64		

are the five last named soils in Table VII which have a total buffer action of 3·2 to 6·4. These five soils are subject to flood from the Sittang river and its tributaries but when flooding is not too serious, all these soils yield excellently and are among the best paddy soils in Burma. The low buffer action of Hmawbi and Palan is attributable to the fact that they are on the old alluvium and the rainfall is very heavy. There is indeed a rough but imperfect correlation between the total buffer action against $N.H_2SO_4$ and the rainfall. The greater the rainfall the smaller the buffer action against $N.H_2SO_4$.

The average of the non-calcareous paddy soils growing paddy under rainfall quoted in Table VII gives the following results, subsoils not being included :

Buffer action against $N.H_2SO_4$ per 1·0 pH = 2·05.

„ „ „ $N.Ba(OH)_2$ „ „ „ = 4·94.

Although insufficient samples have yet been treated to generalize, it appears that the best non-calcareous paddy soils should have a buffer action against $N.H_2SO_4$ equal to not less than 3·0 per 1·0 pH. The value of the buffer action against $Ba(OH)_2$, both total and per unit pH does not seem so important except that it indicates greater leaching and therefore greater lime requirement. The extremely high values for the Kungyaunywa soils are probably connected with the prevalence of floods in that district. In soils of the same type there is a rough correlation between the mechanical texture of the soil and the buffer action against $N.Ba(OH)_2$ per unit pH. Thus in the case of the Tonkan Forest Reserve, Kyeinkagon, Kungyaunywa, Letpangin, Sinyokin and Magyibin soils, the heaviest soils, Kungyaunywa and Magyibin have larger than average buffer action against $Ba(OH)_2$. Mechanical analyses of soils are given in Table VIII. In Table VIII the soil type has been determined by adding together the fractions Clay + Fine Silt, Silt + Fine Sand, Coarse Sand + Fine Gravel and plotting the results within an equilateral triangle divided into six triangles of equal size by joining the apices of the equilateral triangle to the midpoints of opposite sides. In this way six equal triangles were obtained corresponding to soils of varying degree from the heaviest clays to the coarsest sands. The soils have been numbered consecutively from one to six in order of decreasing fineness of texture, *i.e.*, number 1 is the heaviest clay and number 6 the coarsest sand.

With regard to soils other than Lower Burma paddy soils quoted, Mandalay is a heavy calcareous clay. Pwinbyu is a well balanced clay by analysis of ultimate particles. Actually it contains sufficient organic matter to render it moderately free working. Palan and Hmawbi are typical Delta clay soils on the old alluvium. Pyinmana is in the intermediate zone and hence although

the soils are of the loam type the buffer action is fair. Tatkon soil (Chart V) is very similar to that of Pyinmana although lighter than the latter. Tatkon is on the edge of the dry and intermediate zones. The Akyab waterworks soil is the coarsest soil growing paddy that the author has hitherto discovered. Although the rainfall is upwards of 200″ per annum, this would not retain moisture sufficiently well to grow paddy were it not for the fact, that this soil

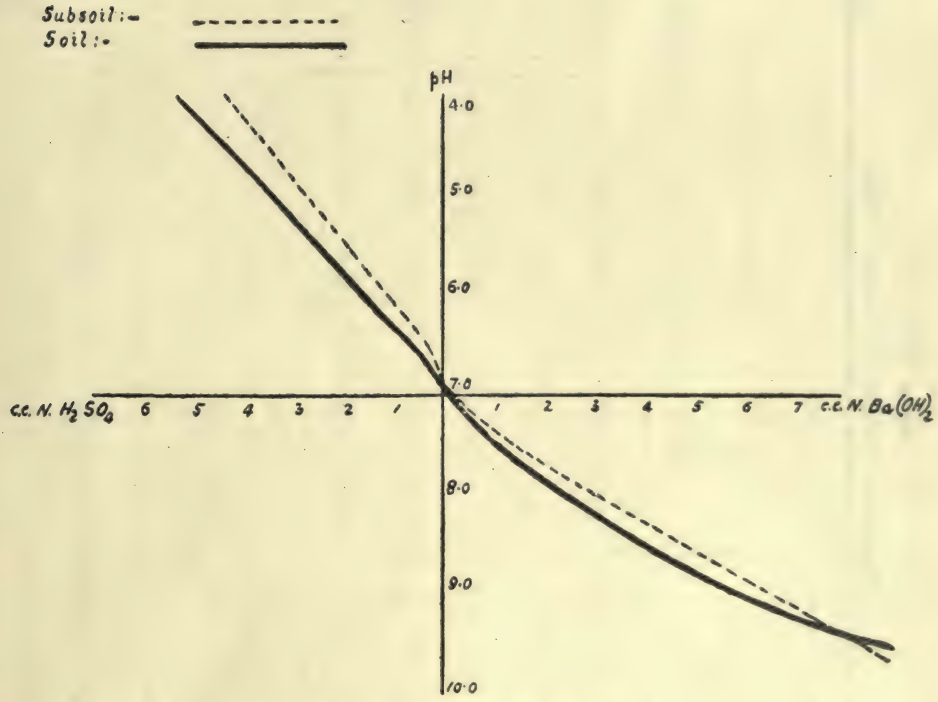

CHART V. Tatkon Farm Soil.

derives an underground supply of water from a reservoir close by. The Mingan soil is a more normal paddy soil but poorly buffered against H_2SO_4 probably on account of the high rainfall.

There is much land of the Palan type which is now yielding only about 1,000 lb. of grain per acre in Lower Burma. It is a noteworthy fact that on the paddy soils Kyeinkagon, Kungyaunywa, Letpangin, Sinyokin and Magyibin a large proportion of the paddy crop becomes laid, particularly a medium lived

TABLE VIII.

Mechanical Analysis of Burma Soils.

	MANDALAY	PWINBYU	HMAWBI	PALAN	TATKON		AKYAB				PYINMANA			
							Waterworks		Mingan		Highest land		Lowest land	
					Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil
Stones and gravel ..	nil	0·01	nil	1·97	0·03	..	0·04	0·46	0·18	0·28	nil	nil	nil	nil
Fine gravel	0·92	0·13	nil	8·05	0·22	..	1·51	..	0·56	2·30	nil	nil	nil	nil
Coarse sand	6·08	0·78	0·73	..	32·28	..	48·37	53·97	0·31	2·50	9·6	10·0	11·6	9·0
Fine sand ..	17·25	12·60	6·67	9·36	35·29	..	16·15	15·08	2·94	2·45	31·0	34·1	42·3	45·2
Silt ..	13·29	35·07	17·44	23·42	13·72	..	12·87	10·45	37·27	33·00	25·5	23·9	21·5	26·6
Fine Silt ..	18·16	31·92	41·25	17·52	9·38	..	13·75	16·94	35·79	34·32	16·2	21·3	15·3	18·1
Clay ..	44·30	19·49	33·91	39·68	9·08	..	6·60	2·86	22·16	24·53	15·9	10·6	9·5	5·3
Type No. ..	1	1	1	1	4	..	6	6	1	1	3	3	3	3
Description	Clay	Clay	Clay	Clay	Light Loam	..	Coarse sand	Coarse sand	Clay	Clay	Loam	Loam	Loam	Loam

TABLE VIII—*contd.*

	Tonkan forest reserve		Kyeinkagon		Kungyaunywa		Letpangin		Sinyokin		Magyibin	
	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil
Stones and gravel ..	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Fine gravel	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Coarse sand	10·6	7·3	16·6	4·2	0·3	0·4	5·2	4·8	14·8	17·1	1·9	1·9
Fine sand	32·9	27·9	36·7	45·1	10·8	6·5	36·1	43·1	42·7	44·0	7·7	10·9
Silt	25·8	26·1	24·0	23·6	36·8	36·0	21·7	21·5	18·8	19·1	35·6	35·6
Fine silt	22·3	28·7	21·1	21·4	41·1	45·2	25·6	21·5	18·0	15·3	36·7	38·7
Clay	9·1	10·4	4·9	7·4	12·2	13·4	9·2	7·3	7·7	6·4	15·8	11·9
Type No.	3	3	3	3	1	1	3	3	3	3	1	1
Description	Loam	Loam	Loam	Loam	Clay	Clay	Loam	Loam	Loam	Loam	Clay	Clay

paddy called Letywezin. Whether this is due to heavy yield, the actual sourness of the soil or the difficulty experienced by the plant in procuring an adequate supply of calcium is an interesting problem and it has been suggested by the author that experiments with lime should be tried. Letywezin is grown only on the sour soils of Lower Burma and is much esteemed as a fair or good yielder.

It is possible to make an interesting comparison between calcareous and non-calcareous soils by estimating the carbonates present in the former and deducting the $N.H_2SO_4$ used in decomposing this carbonate. On this basis the buffer action against $N.H_2SO_4$ per unit pH of the Mandalay soil is only 0·79, the lowest for all the soils quoted. This probably indicates that the reaction with dilute H_2SO_4 is not complete in twenty-four hours but it may indicate that the Mandalay soil lacks an adequate supply of organic matter.

In general the buffer action against $N.H_2SO_4$ per unit pH is greater in the soil than in the subsoil, the case of Akyab soils being an exception. Where both soil and subsoil are free from $CaCO_3$ and the soil does not contain more colloidal clay than the subsoil, the greater buffer action of the soil may be attributed to its higher content of organic matter. This suggests a method of amelioration of soils poorly buffered against sourness, *viz.*, by green manuring, although better results would probably be obtained by liming in conjunction with green manuring.

IV. CONCLUSIONS.

1. The range of fertility of soils is assumed to lie between the limits pH 4·5 and pH 9·5.

2. The buffer action of soils against sourness and alkalinity may be determined by shaking soil for twenty-four hours at 30°C. with H_2SO_4 or $Ba(OH)_2$ solution respectively and measuring the pH values of the soil solutions obtained. The centrifugal method of clearing the solutions is preferred. From the pH values obtained, titration curves are plotted.

3. From the titration curves, the lime requirement of a soil may be read at any particular pH value. By dividing the number of cubic centimetres of $N.Ba(OH)_2$ absorbed by twenty, the lime requirement per cent. for adjusting the reaction of the soil to the particular pH value required is obtained.

4. A measure of the total buffer action against increasing sourness or increasing alkalinity is given by the number of cubic centimetres of $N.H_2SO_4$ or $N.Ba(OH)_2$ respectively required to transform the reaction of the soil from its existing value to pH 4·5 and pH 9·5, results being expressed per 100 grm. soil dried to constant weight at 100°C.

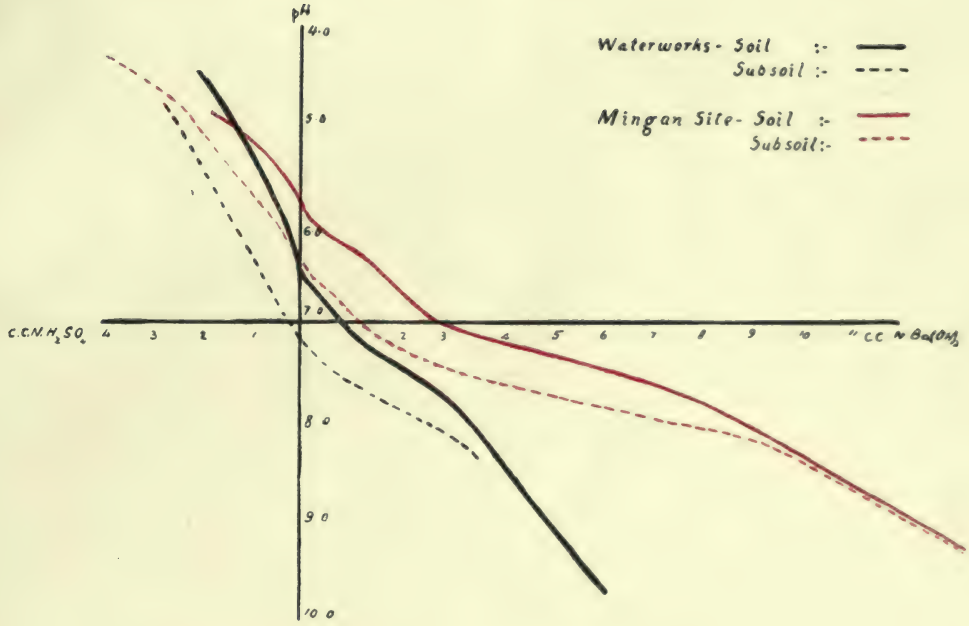

Chart VI. Akyab Soils.

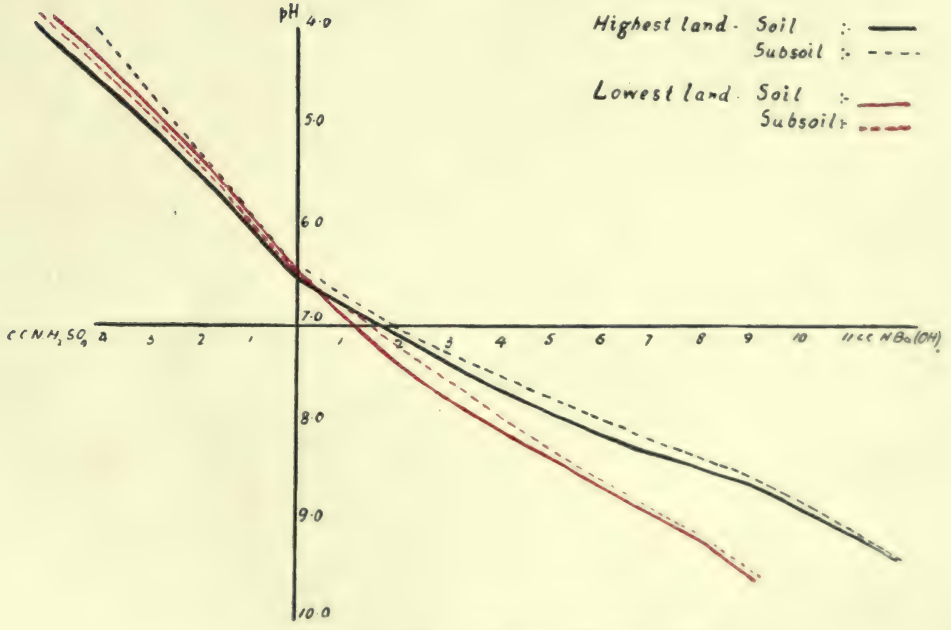

Chart VII. Pyinmana Farm Soils.

5. The buffer action of soils against acid and alkali respectively may be expressed as

$$(a)\ \frac{\text{c.c. N.H}_2\text{SO}_4 \text{ used}}{X-4{\cdot}5}$$

$$(b)\ \frac{\text{c.c. N.Ba(OH)}_2 \text{ used}}{9{\cdot}5-X}$$

where X is the existing pH value of the soil and the weight of soil used is equal to 100 grm. dried to constant weight at 100°C.

6. A selection of non-calcareous Burma soils growing paddy exclusively under rainfall gives a value for buffer action against acid per unit of pH varying from 0·92 to 3·42 with a mean of 2·04. The better soils have the higher values. Sour paddy soils should have a value of not less than 3·0.

7. Buffer action against alkali is relatively unimportant in the soils examined. In the non-calcareous paddy soils the average value per unit of pH was 4·94, the more productive soils having the higher value. The only inference which can be drawn with any certainty in such cases is that the higher the buffer action against alkali, the greater the lime requirement over certain pH ranges.

The author desires to acknowledge his indebtedness to Mr. S. P. Aiyar, B.A., who has determined all the pH values of the soils quoted except such as were necessary in standardizing the method adopted.

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